PICTURE DISPLAY OF REAR SURFACE PROJECTION TYPE

FIELD OF THE INVENTION

The invention relates to a picture display of the rear

5   surface projection type, and especially to a picture display of

the rear surface projection type in which a light flux modulated

by a picture is projected on a rear surface of a transparent screen,

and the projected picture is enjoyed by a user from the front side

of the transparent screen.

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BACKGROUND OF THE INVENTION

Some of the picture displays of the rear surface projection

type developed in recent years are provided with built-in

picture-forming units, such as liquid crystal light valves or

15   digital mirror devices. In the aforementioned apparatus, the

light flux outputted from the light source is modulated by the

picture generated in the picture-forming unit, shot out from the

projector, and projected on the rear surface of the transparent

screen. The picture projected on the screen is enjoyed by a user

20   from the front side of the transparent screen.

However, if the picture display of the rear surface

projection type is used in such a condition that the optical axis

of the projector is intersected with the transparent screen

perpendicularly, the distance between the projector and the

25   transparent screen cannot be shortened, and it becomes difficult

to make the picture display thin. In order to solve the

aforementioned problem, it is the general trend that the angle

of view of a projection optical system of the projector is widened,

the projector is shifted down to a position lower the transparent screen, and the light flux shot out from the projector is projected on the rear surface of the transparent screen obliquely.

However, in the aforementioned picture display of the rear surface projection type, since the incidence angle of the light flux incident on the transparent screen becomes large, and thereby the greater part of the incident light flux is reflected at the rear surface of the transparent screen and cannot be transmitted thereinto, the brightness of the picture becomes low when viewed from he front side of the screen, and the quality of the picture is degraded.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the invention to provide a picture display of the rear surface projection type in which an incident light flux is efficiently transmitted into a transparent screen even when an incidence angle of a light flux increases because of the widened angle of view of a projection optical system, and the brightness and the quality of a picture are certainly prevented from being degraded because of reflection of an incident light flux at a rear surface of a transparent screen, and a picture with the excellent quality can be enjoyed.

According to the feature of the invention, a picture display of the rear surface projection type comprises:

a projector for shooting out a light flux modulated by a picture,

a transparent screen, on a rear surface of which the light flux shot out from the projector is projected, and

a sawlike prismatic surface which is formed on the rear surface of the transparent screen, and provided with plural edges shaped into concentric circles centering around a central point situated outside the transparent screen,

5   wherein an optical axis of the projector passes through the central point, and

a ray of light incident on a first face looking downward and neighboring with each of the plural edges is efficiently transmitted into the transparent screen, and the ray of light

10   transmitted through the first face is totally reflected by a second face looking upward and neighboring with the same edge to a front surface of the transparent screen, in case that a angle formed by the ray of light incident on the first face and the optical axis of the projector is greater than $40°$ and less than $90°$.

15   In the picture display of the rear surface projection type according to the invention, when the angle formed by the optical axis of the projector and the ray of light incident on the first face is greater than $40°$ and less than $90°$, the ray of light incident on the first face looking downward and neighboring with

20   each edge formed on the sawlike prismatic surface is efficiently transmitted into the transparent screen, and totally reflected by the second face looking upward and neighboring with the same edge to the front surface of the transparent screen. Accordingly, even in case that the angle of view of the projection optical system

25   is widened, and thereby the incidence angle of the light flux incident on the transparent screen increases, the incident light flux is efficiently transmitted into the transparent screen, and can be totally reflected to the front surface thereof.

Accordingly, the brightness and the quality of the picture are certainly prevented from being degraded, and the picture with the excellent quality can be enjoyed by the user.

In order to achieve the aforementioned object of the
5   invention, an angle α_2 formed by the first face and a line perpendicular to the optical axis of the projector is given by a following equation that

$$\tan \alpha_2 = \left[\, n_2 \sin \left\{ \, \sin^{-1}\left(\, (\, n_3 / n_2) \, \sin \theta_2 + \, n_1 \sin \theta_1 \right) + 2\alpha_1 \right\} + \, n_1 \sin \theta_1 \right] / $$

$$\left[\, n_1 \cos \theta_1 - n_2 \cos \left\{ \, \sin^{-1}\left(\, (\, n_3 / n_2) \, \sin \theta_2 + \, n_1 \sin \theta_1 \right) + 2\alpha_1 \right\} \right] ,$$

10   wherein a refractive index of the first medium brought into contact with the sawlike prismatic surface of the transparent screen is denoted by n_1, a refractive index of the second medium forming the transparent screen is denoted by n_2, a refractive index of the third medium brought into contact with a front surface of
15   the transparent screen is denoted by n_3, an angle formed by the ray of light incident on the first face and the optical axis of the projector is denoted by θ_1, a refraction angle of a ray of light shot out from the front surface of the transparent screen is denoted by θ_2, and an angle formed by the first and second faces
20   is denoted by α_1.

When the refractive indexes n_1 to n_3, the angle θ_1 formed by the optical axis of the projector and the ray of light incident on the first face looking downward, etc. are given in the process for fabricating the sawlike prismatic surface, the angle α_2 (the
25   Fresnel angle) are determined from the above equation, and the

structure of the sawlike prismatic surface in which various incommoditeis, such as the surface reflection of light etc., can be avoided is uniquely determined.

In order to achieve the aforementioned object of the 5 invention, a transmission efficiency η of the ray of light incident on the sawlike prismatic surface is given by a following equation that

$$\eta = \sin \alpha_2 \cos \alpha_2 \left\{ \tan \left(90^\circ - \alpha_2 \right) + \tan \theta_1 \right\} \left\{ \left(1/\tan \alpha_1 \right) - \tan \theta_{1b} \right\} \quad ,$$

wherein θ_{1b} is a refraction angle of the ray of light incident 10 on the first face looking downward of the sawlike prismatic surface. If α_1 such that η is greater that 1 is determined from the above equation, the picture with the excellent quality can be obtained without attenuating its brightness.

Moreover, it is desirable to form a light absorption layer 15 for absorbing an external light penetrating into the transparent screen through a front surface thereof on an external surface of each of the second faces looking upward. For example, if the external light penetrates into the transparent screen through the front surface thereof toward the rear side, there arises a 20 possibility that the external light will be scattered diffusedly by inner surfaces of a casing for accommodating the transparent screen, and undesired images (ghosts) will be formed at irregular positions on the picture. However, if the aforementioned structure is adopted, since the external light is absorbed by the 25 light absorption layer and not transmitted toward the rear side, the undesired images can be certainly prevented from being formed.

BRIEF DESCRIPTION OF DRAWINGS

The invention will be explained in more detail in conjunction with appended drawings, wherein:

FIG.1 is a perspective view for showing a fundamental structure of a picture display of the rear surface projection type according to a preferred embodiment of the invention,

FIG.2A shows a back view of a transparent screen used in a picture display of the rear surface projection type shown in FIG.1,

FIG.2B shows a cross-sectional view of the transparent screen shown in FIG.2A taken along a line b-b,

FIG.3 is a cross-sectional view for showing optical paths of a ray of light incident on a sawlike prismatic surface formed on a transparent screen shown in FIGs.2A, 2B,

FIG.4 is a cross-sectional view for showing an example for comparison concerning with the aforementioned embodiment of the invention, and

FIG.5 is a cross-sectional view for showing a structure of a modified transparent screen, on the sawlike prismatic surface of which a light absorption layer is formed.

DESCRIPTION OF PREFERRED EMBODIMENT

Hereafter, a preferred embodiment of the invention will be explained in detail referring to the drawings. FIG.1 is a perspective view for showing a fundamental structure of a picture display of the rear surface projection type. The picture display of the rear surface projection type 10 is composed of a transparent screen 11, and a liquid crystal projector 12 for projecting a light

screen 11. The projected picture is enjoyed by a user from the front side of the transparent screen 11.

The transparent screen 11 is approximately shaped into a rectangular plate formed of glass or transparent plastics, and 5 a sawlike prismatic surface 15 is formed on the rear surface thereof. The sawlike prismatic surface 15 is provided with plural edges 15A which are shaped into concentric circles centering around a central point 18 to form a Fresnel lens, where the central point 18 is on an intersection of the optical axis 17 of the liquid crystal 10 projector 12 and a downward extension of the sawlike prismatic surface 15.

The liquid crystal projector 12 is composed of a light-supplying unit 13 containing a light source (not shown) and a picture-forming unit (not shown) therein and a projection optical 15 system 14 for projecting the light flux modulated by a picture on the rear surface of the transparent screen 11. The liquid crystal projector 12 is so constructed that half the angle of view W which is defined as an angle formed by the optical axis 17 of the projector 12 and the outermost light of the light flux projected 20 on the transparent screen 11 is less than $90°$.

FIG.2A is a back view of the transparent screen 11, and FIG.2B is a cross-sectional view of the same taken along a line b-b.

As shown in FIG.2A, the surface of the sawlike prismatic surface 15 is formed of the plural edges 15A shaped into the 25 concentric circles centering around the central point 18. As shown in FIG.2B, the plural edges 15A project towards the right side on the rear surface of the transparent screen 11. On the other hand, a light-shooting out surface 16 with a flat face is formed

on the front of the transparent screen 11.

FIG.3 partially enlarges a portion of FIG.2B, and is a cross-sectional view of showing paths of a ray of light incident on the sawlike prismatic surface 15. As shown in FIG.3, the sawlike prismatic surface 15 includes plural prisms, each of which is formed of a face 15a looking downward and neighboring with an edge 15A and the other face 15b looking upward and neighboring with the same edge 15A, where the vertex angle formed by the faces 15a, 15b is given as α_1. As explained referring to FIGs. 1, 2A formerly, the shape of each edge 15A is circular, when viewed from the side of the liquid crystal projector 12. Now, as shown in FIG.3, an angle formed by the ray of light B_1 incident on the face 15a looking downward (in other words, incident on the sawlike prismatic surface 15) and a line 19 which is parallel to the optical axis 17 of the projector 12 is denoted by θ_1, and θ_1 is assumed to be greater than $40°$ and less than $90°$. The sawlike prismatic surface 15 used in the embodiment is so contracted that, if the aforementioned conditions are satisfied, the ray of light B_1 incident on the face 15a looking downward is efficiently transmitted into the transparent screen 11, and the ray of light incident on the face 15b looking upward is totally reflected to the light-shooting out surface 16.

For example, when the ray of light B_1 contained in a light flux outputted from the liquid crystal projector 12 is intersected with the face 15a at an incidence point, a normal of the face 15a and the line 19 parallel to the optical axis 17 of the projector 12 are respectively drawn at the incidence point. The incidence angle of the ray of light B_1 is denoted by θ_{1a}. If the incident ray

of light B_1 is the outermost one of the light flux outputted from the projector 12, θ_1 becomes equal to half the angle of view W of the projector 12.

The ray of light B_1 incident on the face 15a at the incidence

5   of θ_{1a} is efficiently transmitted into the transparent screen 11, because the incidence angle θ_{1a} is small. As shown in FIG.3, the refraction angle of the refracted ray of light is denoted by θ_{1b}. Moreover, the ray of light incident on the face 15b situated opposite to the face 15a is totally reflected to the light

10   shooting-out surface 16. In this case, the refraction angle of the ray of light shot out from the light-shooting out surface is given as θ_2.

In order to realize the functions of introducing the ray of light B_1 incident on the face 15a looking downward into the

15   transparent screen 11 efficiently, and of totally reflecting the ray of light incident on the face 15b looking upward to the front surface 16 of the transparent screen 11, the sawlike prismatic surface 15 can designed in accordance the equations mentioned later.

20   That is to say, if the refractive index of the first medium (such as air) which is brought into contact with the sawlike prismatic surface 15 formed on the transparent screen 11 is denoted by n_1, the refractive index of the second medium forming the transparent screen 11 is denoted by n_2, the refractive index of

25   the third medium (such as air) which is brought into contact with the light-shooting out surface 16 of the transparent screen 11 is denoted by n_3, the angle formed by the optical axis 17 and the ray of light B_1 incident on the face 15a looking downward is denoted

by θ_1, the refraction angle of the refracted ray of light at the light-shooting out surface 16 of the transparent screen 11 is denoted by θ_2, the vertex angle of the edge 15A formed by the faces 15a, 15b is denoted by α_1, and the angle formed by the light-

5   shooting out surface 16 and the face 15a looking downward is denoted by α_2, $\tan\alpha_2$ is given by the following equation that

$$\tan\alpha_2 = \left\lfloor n_2 \sin\left\{\sin^{-1}((n_3/n_2)\sin\theta_2 + n_1\sin\theta_1) + 2\alpha_1\right\} + n_1\sin\theta_1\right\rfloor /$$

$$\left[n_1\cos\theta_1 - n_2\cos\left\{\sin^{-1}((n_3/n_2)\sin\theta_2 + n_1\sin\theta_1) + 2\alpha_1\right\}\right],$$

      The transparent screen 11 having the sawlike prismatic

10   surface 15 which has the function of totally reflecting the ray of light incident on the face 15b looking upward to the light-shooting out surface 16, when the angle θ_1 formed by the ray of light B_1 incident on the face 15a looking downward and the optical axis 17 of the liquid crystal projector 12 is greater than

15    $40°$ and less that $90°$, can be realized by determining the Fresnel angle α_2 satisfying the above equation. It should be noted that the aforementioned condition imposed on the angle θ_1 is automatically satisfied in case that an angle formed by the outermost light of the light flux outputted from the projector

20   12 and the optical axis 17 of the projector 12 is $90°$, and an angle formed by the innermost light of the same light flux and the same optical axis is $40°$. According to the aforementioned structure, even in case that half the angle of view W of the projector 12 is made close to $90°$, and the liquid crystal projector 12 closely

25   approaches the transparent screen 11 in FIG.1, the ray of light

B_1 incident on the rear surface of the transparent screen 11 at a large incidence angle can be certainly directed to the light-shooting out surface 16, so that the picture display of the rear surface projection type 10 can be further thinned down
5 according to the invention.

Moreover, if the refraction angle of the ray of light incident on the face 15a looking downward and neighboring with the edge 15A is denoted by θ_{1b}, the light transmission efficiency η of the transparent screen 11 having the sawlike prismatic
10 surface 15 can be made 100 %, and a satisfactory picture can be obtained without attenuating brightness.

Herein, an example for comparison with respect to the picture display of the rear surface projection type 10 according to the embodiment will be explained. FIG.4 is a partially enlarged
15 cross-sectional view for showing a transparent screen according to the aforementioned example for comparison. The order of arrangement of the sawlike prismatic surface 15 and the light-shooting out surface 16 in the transparent screen 11 according to the embodiment shown in FIG.3 is inverted in that
20 shown in FIG.4 for showing the example for comparison.

For simplicity of explanation, B_1 shown in FIG.4 will be expressed as a light flux. The light flux B_1 outputted from the liquid crystal projector 12 (see FIG.1) reaches the flat surface 16 which served as the light-shooting out surface 16 of the
25 transparent screen 11 in the embodiment shown in FIG.3, and is shot out from the sawlike prismatic surface 15 after passing through the transparent screen 11. In this case, the greater part of the light flux B_1 incident on the flat surface 16 is reflected,

because the incidence angle of the light flux B_1 is large. The remains of the light flux B_1 is transmitted into the transparent screen 11, refracted by the boundary surface 15b, and observed from the outside. In case that the transparent screen 11 is observed from the outside, the brightness is lowered because of reflection of the light flux B_1 at the flat surface 16, and the quality of the picture is degraded.

However, in the picture display of the rear surface projection type 10 according to the invention, when the angle θ_1 shown in FIG.3 is greater that $40°$ and less that $90°$, the ray of light B_1 incident on the face 15a looking downward is efficiently transmitted into the transparent screen 11, and totally reflected by the face 15b looking upward to the light shooting-out surface 16. Accordingly, even in case that half the angle of view of the liquid crystal projector 12 increases, and the incidence angle of the ray of light incident on the transparent screen 11 is increases, the ray of light B_1 incident on the transparent screen 11 can be efficiency transmitted therethrough, and the picture clearly projected on the transparent screen 11 can be enjoyed by the user sitting beyond the projector 12.

Thereupon, if the external light incident on the front (left) surface of the transparent screen 11 passes therethrough, there arises a possibility that the external light will be scattered diffusedly by inner surfaces of a casing for accommodating the transparent screen 11, and undesired images (ghosts) will be formed at irregular positions on the transparent screen 11. So, as shown in FIG.5, the faces 15b looking upward and neighboring with the edges 15A on the sawlike prismatic surface 15 are stained with

black ink to form light absorption layers 33. Accordingly, the external lights B_2 penetrating into the inner space of the transparent screen 11 can be absorbed by the light absorption layers 33 certainly, and the ghosts can be suppressed.

5   As mentioned in the above, according to the picture display of the rear surface projection type according to the invention, even in case that the angle of incidence of the light flux incident on the tarnsparent screen is increased because of the wide angle of view of the projection optical system originating in the thinned

10   projector, the light flux can be efficiently transmitted into the transparent screen, and totally guided to the light-shooting out surface of the same. Accordingly, the brightness and the quality of the picture can be certainly prevented from being degraded because of reflection of light at a boundary surface between media,

15   and the user can enjoy the picture with the excellent quality.

          Although the invention has been described with respect to specific embodiment for complete and clear disclosure, the appended claims are not to be thus limited but are to be construed as embodying

20   all modification and alternative constructions that may be occurred to one skilled in the art which fairly fall within the basic teaching herein set forth.